Efficiency characterization of the ATLAS diphoton and combined photon plus multijet triggers using PHYSLITE derivations, with applications to Stealth SUSY searches

Joaquín Iturriza Ramírez

Supervisor: Joaquín Hoya

ATLAS Experiment, CERN, Summer School Programme

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Abstract

The ATLAS experiment in the LHC Run-3 is recording up to 3 kHz of fully-built physics collision events out of an LHC bunch crossing rate of up to 40 MHz. A two-level trigger system selects events of interest to cover a wide variety of physics while rejecting a high rate of background events. The selection of events targets both generic physics signatures, such as photons, jets, missing energy, as well as more specific signatures targeting specific physics events, from Standard Model processes to searches for new phenomena. Triggering these particles is essential for signal selection, and also for calibration, efficiency and fake rate measurements. As part of the ATLAS physics programme, the SUSY Strong Stealth analysis targets an uncovered phase space with a final state featuring 2 photons, at least 6 jets and no missing energy. The considered triggers, although are generic in the sense that multiple analysis will use them, are going to be used by this search for event selection and data-driven background estimation techniques.

1 Introduction

Even though the Standard Model is one of the most successful and precise theories in all of physics, there are many unsolved problems that suggest the SM is not the full picture. One of the theories beyond the Standard Model that tries to solve some of these problems is Supersymmetry (SUSY), proposing that every particle has a corresponding 'superpartner' particle, sharing mostly the same properties, but differing in spin in a half integer amount, so that every boson has an associated fermion, and vice-versa, coming from an underlying symmetry between matter and the interaction forces [1].

There is no better place to test these theories than the ATLAS Experiment in the Large Hadron Collider at CERN, the biggest detector in the most powerful particle collider in the world. To do it, the trigger and data acquisition system of ATLAS saves potential SUSY related events for further analysis.

The aim of this project is to test the efficiency the trigger and data acquisition system of ATLAS at identifying interesting events for a particular SUSY model, Stealth SUSY.

1.1 Stealth SUSY

SUSY models come in many shapes and sizes, a popular explanation to the lack of experimental evidence for SUSY is that all superpartners lay in a 'hidden sector', meaning that they almost don't interact with SM particles, and are only weakly coupled by messenger particles. One proposed model that's particularly interesting for searches in particle colliders is Stealth SUSY, specifically a Minimal Stealth model, where the mass split between a singlet particle and it's superpartner, the singlino, is very small, leading to soft decay products, small missing energy and recognizable detector signatures [2]. Ignoring the messenger particles, the relevant decay chain is illustrated in Fig. 1.

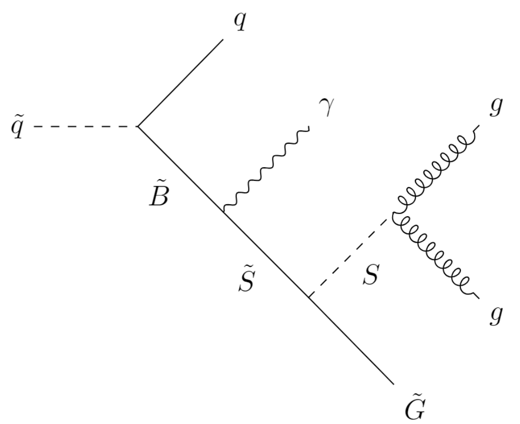

Figure 1: Feynman diagram of the decay chain for the Stealth SUSY process relevant to the triggers studied.

A squark decays into a quark and a bino, the bino emits a photon and decays into a singlino, which decays into a soft gravitino and a singlet, finally the singlet decays into two gluons. This means that every pair of squarks could result in six jets and two photons with very low missing energy being carried by the gravitinos.

1.2 ATLAS detector

The ATLAS experiment [3] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near 4π coverage in solid angle. It consists of an inner tracking detector surrounded by a thin superconducting solenoid providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer. The inner tracking detector covers the pseudorapidity range $|\eta| < 2.5$. It consists of silicon pixel, silicon microstrip, and transition radiation tracking detectors. Lead/liquid-argon (LAr) sampling calorimeters provide electromagnetic (EM) energy measurements with high granularity. A steel/scintillator-tile hadron calorimeter covers the central pseudorapidity range ($|\eta| < 1.7$). The endcap and forward regions are instrumented with LAr calorimeters for both the EM and hadronic energy measurements up to $|\eta| = 4.9$. The muon spectrometer surrounds the calorimeters and is based on three large superconducting air-core toroidal magnets with eight coils each. The field integral of the toroids ranges between 2.0 and 6.0 T·m across most of the detector. The muon spectrometer includes a system of precision tracking chambers and fast detectors for triggering.

1.3 Trigger

A two-level trigger system [4] is used to select events of interest. The first-level (L1) trigger is implemented 'online' directly on hardware, reducing the event rate from the 40 MHz bunch crossing rate to below 100 kHz; with only 2.5 µs to decide which events to keep, L1 has to be optimized and incredibly fast. After accepting one event as interesting, L1 defines so called regions-of-interest (RoIs), being places in the detector with a lot of deposited energy, muon traces, etc.

Events accepted by L1 are processed by the high-level trigger (HLT), this is done in software, and with more complicated algorithms, since there is more time to make a decision. This is done to further reduce the amount of data saved to around 1 kHz. The HLT uses more sophisticated information not available at L1 to make decisions, either within the RoIs identified at L1 or for the full detector (full-scan). The selection of particle candidates by the HLT is performed at each step, so that if it fails at a certain step, subsequent steps are not executed. This is essential to reduce the time needed by the HLT to reconstruct the event and make a decision.

A sequence of L1 and HLT trigger algorithms is called a 'trigger chain' and is meant to identify one or more particles of a given type and a given threshold of transverse energy or momentum. For example, electron and photon triggers are meant to select events with one or more electrons or photons in the detector. The configuration of the trigger is controlled by the 'trigger menu', which defines a full list of the L1 and HLT triggers and their configurations. Menu composition and trigger thresholds are optimised for the LHC running conditions (beam type, luminosity, etc.) to fit within the event acceptance rate and the bandwidth constraints of the data acquisition system of the ATLAS detector as well as the offline storage constraints.

This project focuses on the efficiency of one trigger relevant to the physics described in Section 1.1, `HLT_g35_loose_g25_loose` for 2015 and 2016; which in 2017, 2018 and 2022 is `HLT_g35_medium_g25_medium`. Analysis setup was developed and ready to compute efficiencies of `HLT_2g50_loose_L12EM20VH` and `HLT_g45_loose_6j45_0eta240`, also including 2022 data as next steps, due to unexpected issues with the data this was not possible, everything is ready to do it whenever the data is available.

Efficiency is calculated, on top of the common preselection for each trigger, as

$$\epsilon = \frac{\text{\# events that pass the trigger and the BS triggers}}{\text{\# events that pass the BS triggers}}.$$

2 Bootstrapping

To calculate the efficiencies, one must generate an unbiased sample from all the recorded data, this can be done in many ways and one way to do it is called *bootstrapping* or creating a bootstrap (BS) sample. One way to create an unbiased BS sample is to just sample events at random until the desired size of the BS sample is met. Another interesting way is to only use events that pass one or more unrelated triggers to the trigger of interest. For example, since muons don't play a role in the processes previously described, one could generate a BS sample with events that pass any muon trigger. In practice, one downside to this method is that, bringing back the muon example, to generate a BS sample with only events passing a muon trigger and then calculating the efficiency of the desired trigger would restrict the calculations to events with two photons, six jets and a muon, such events are rare, leading to small sample sizes and low statistical significance. It's important to find a balance between getting a big enough sample size and not introducing a bias in the sampling process.

For this project, the BS samples were generated by events passing any electron or muon trigger, only using electron triggers with low transverse momentum, since to the L1 triggers photons and electrons look the same, using high p_T could bias the sample.

3 Efficiency

For the `HLT_g35_loose_g25_loose` trigger, the efficiency as a function of the leading photon transverse momentum and as a function of η of the leading photon is shown in Fig. 2 and Fig. 3 respectively for 2015 and 2016 data, also, in Fig. 4 the efficiency as a function of the pile-up only for 2016 data is shown. The graphs as a function of η and pile up, μ, where made with events with leading photon $p_T > 40$ GeV, in order to be on the plateau of the efficiency.

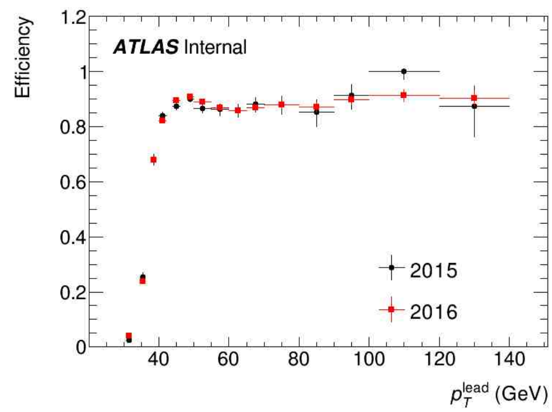

Figure 2: Efficiency of the `HLT_g35_loose_g25_loose` trigger as a function of the leading photon transverse momentum, for 2015 data in black and 2016 data in red.

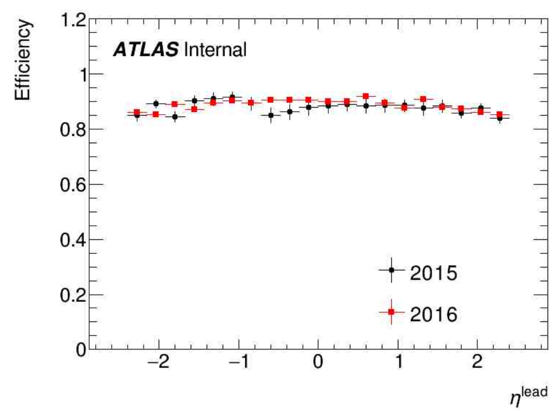

Figure 3: Efficiency of the `HLT_g35_loose_g25_loose` trigger as a function of the leading photon η, for 2015 data in black and 2016 data in red.

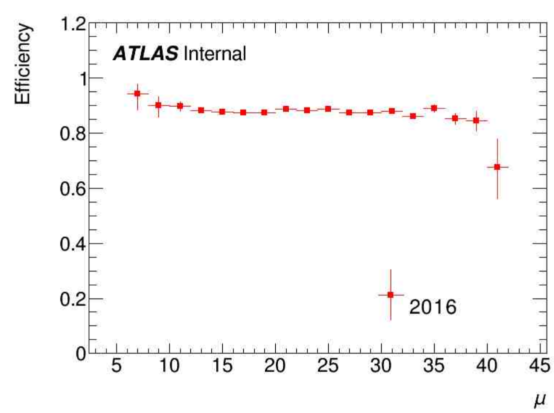

Figure 4: Efficiency of the `HLT_g35_loose_g25_loose` trigger as a function of the pile up, for 2016 data.

In Fig. 2 it is appreciable a sharp turn on of the efficiency starting at 35 GeV, and settling at around 90%

from 45 GeV onwards, which is the expected behaviour for this trigger. In Fig. 3 the efficiency is also near 90% across almost all values of η, with a slight decrease in efficiency for large values of $|\eta|$. Finally, it's clear the effect pile up has on efficiency from Fig. 4, where it is 90% for almost all pile up values, increasing for lower pile ups, and decreasing for high values, this is again in line with what is expected.

In the appendix are shown the same efficiencies, but only taking into account events with at least 1 jet, 2 jets, ..., up to at least 6 jets.

4 Conclusion

The aim of this project was to calculate the efficiency of the `HLT_g35_loose_g25_loose`, and study it's behaviour in relation to different variables. To that end, the efficiencies found were high, around 90%, the behaviour of the triggers was as expected, with a sharp turn on as a function of the leading photon transverse momentum, and generally uniform as a function of the pile up and the leading photon η.

Everything is ready to study the data for the remaining years and triggers when the data is available, and the full analysis will be hopefully shown at the Reunión Anual de Física Argentina.

References

[1] Stephen P. Martin. A Supersymmetry Primer. In *Perspectives on Supersymmetry*, pages 1–98. World Scientific, jul 1998.

[2] JiJi Fan, Matthew Reece, and Joshua T. Ruderman. Stealth supersymmetry. *Journal of High Energy Physics*, 2011(11), nov 2011.

[3] ATLAS Collaboration. The ATLAS Experiment at the CERN Large Hadron Collider. *JINST*, 3:S08003, 2008.

[4] Morad Aaboud et al. Performance of the ATLAS Trigger System in 2015. *Eur. Phys. J. C*, 77(5):317, 2017.

Appendix

Here are shown the efficiencies calculated only with events containing at least 1 jet, 2 jets, ..., respectively up to at least 6 jets, for p_T^{lead} in Fig. 5, η^{lead} in Fig. 6 and pile up in Fig. 7.

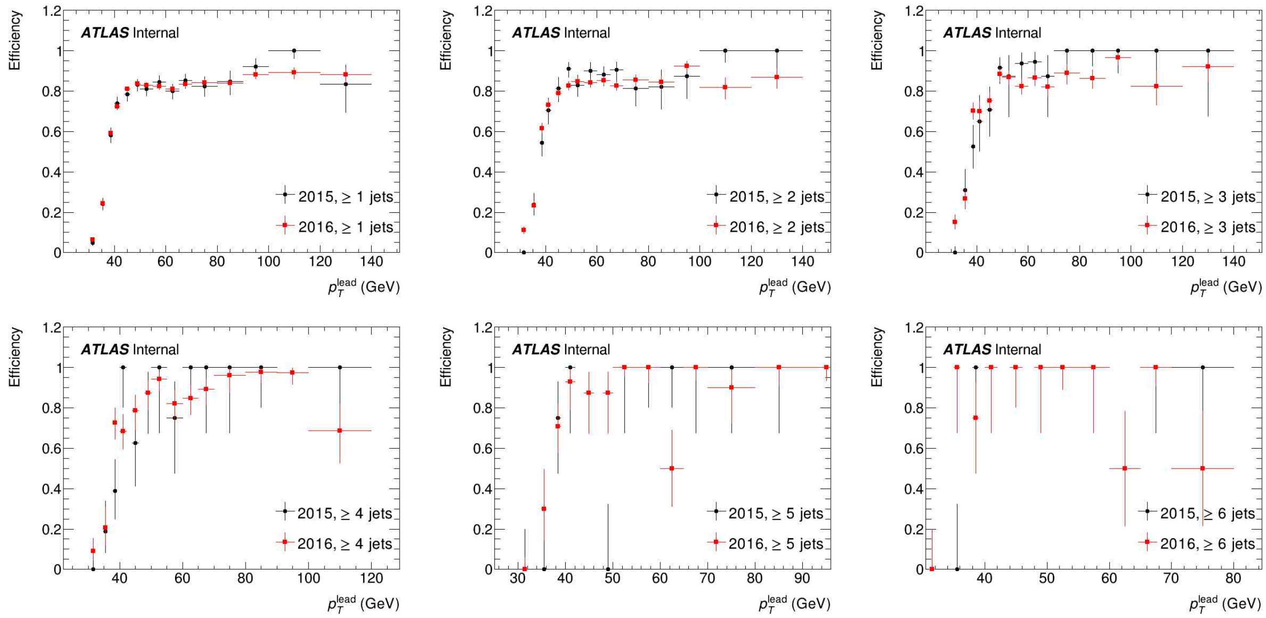

Figure 5: Efficiencies of the `HLT_g35_loose_g25_loose` trigger as a function of the leading photon transverse momentum, for 2015 data in black and 2016 data in red, calculated with events with at least n jets.

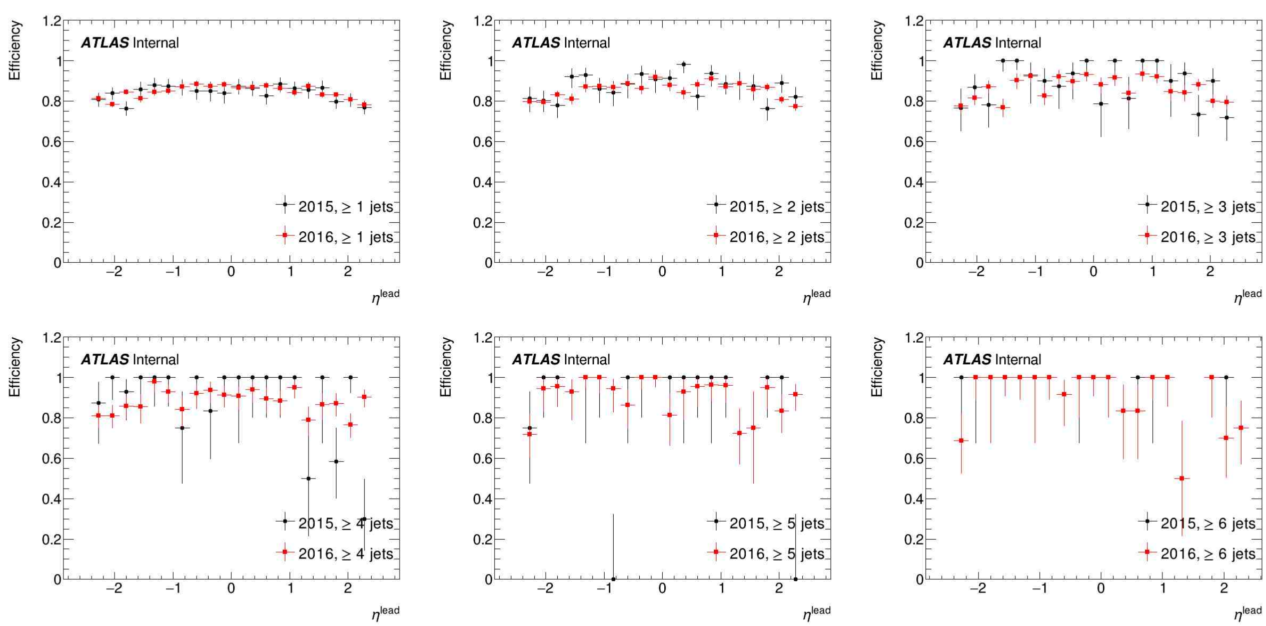

Figure 6: Efficiencies of the `HLT_g35_loose_g25_loose` trigger as a function of the leading photon η, for 2015 data in black and 2016 data in red, calculated with events with at least n jets.

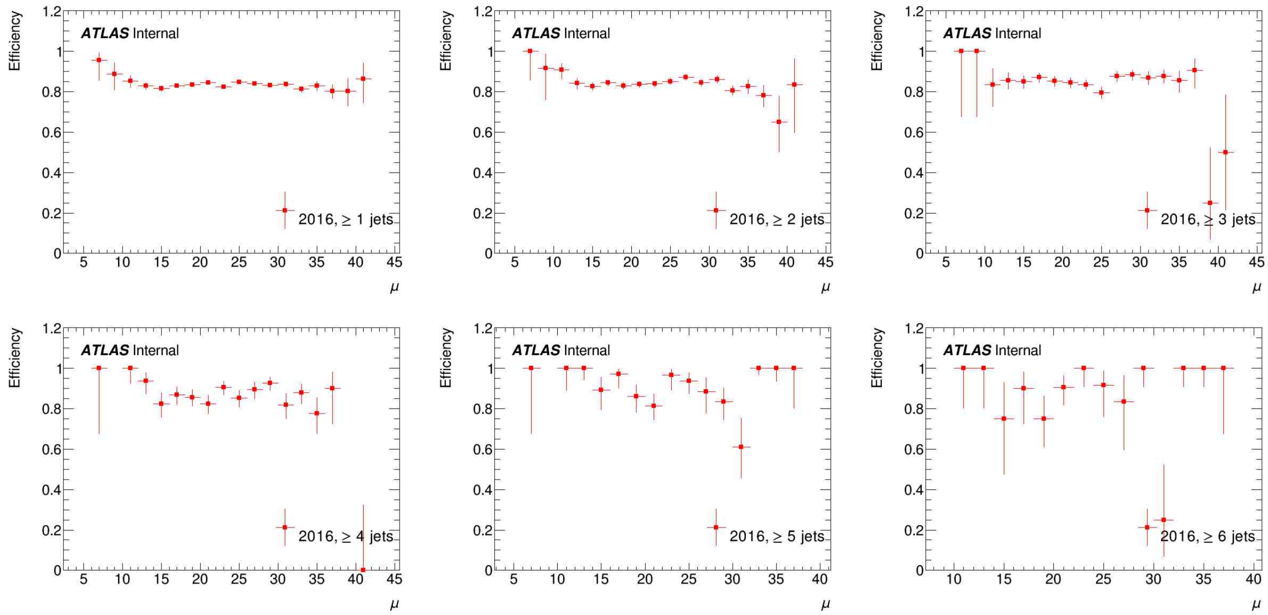

Figure 7: Efficiencies of the `HLT_g35_loose_g25_loose` trigger as a function of the pile up, for 2016 data, calculated with events with at least n jets.

Because the events become more and more rare, there isn't enough data to have statistical significance in some of these plots, however the same conclusions can be made as before, with a lower degree of confidence. To get more data, more BS triggers could be added to generate a bigger BS sample.